NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM 190

LONGITUDINAL BALANCING OF AIRPLANES.

By Albert Eteve.

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One of the most important operations in the completion of an airplane consists in verifying the center of lift, the constructo having had only the information furnished by the aerodynamic laboratory from tests on small models. This information is usually sufficient, but, due to inevitable differences in weight and drag of the various parts of the airplane, as designed and as constructed, it is absolutely necessary to correct the center of lift, the accuracy of which is usually determined by the test pilots.

Moreover, on airplanes in use the center of gravity gradually shifts, due to variations in the weight of certain parts (engine, radiator, etc.) or in the drag (due to warping, roughening of the surfaces, etc.). Here again tests of the center of lift are necessary and must often be followed by important corrections, often impossible to accomplish, because the constructor had made no provision for adjustments.

The object of the present communication is to determine the best method for locating the center of lift of an airplane and to provide a method for making corrections.

The method employed is very simple, being based on the positions given the elevator during flights at different speeds. The elevator, in fact, produces a couple which offsets the couple resulting from variations in the center of lift.

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* From "Premier Congrès International de la Navigation Aérienne," Paris, November, 1921, Vol. IV, pp. 469-475.

Let us refer to the diagram prepared in the Eiffel Laboratory relative to the variations in the center of lift of the Hanriot airplane (p. 125 of the "Resumé des derniers travaux exécutés pendant la guerre") (Fig. 1). This diagram furnishes, for each position of the elevator, a curve whose abscissas are the positions of the center of lift and whose ordinates are the corresponding angles of attack. We thus find that stability is assured for all practical angles of attack corresponding to a certain position of the center of gravity, only when the vertical line from this point encounters none of the branches corresponding to points of unstable equilibrium. Can a diagram be drawn for a full-sized airplane, in order to make the same verification?

It would seem much simpler to transform this diagram by taking the angles of attack as abscissas and the positions of the elevator as ordinates. We thus obtain a set of curves corresponding to various positions of the center of lift. E.g., curve 40 of Fig. 2 furnishes all the values of the angles of attack and of the corresponding positions of the elevator, for which the center of lift is located at 40% of the wing chord. The curves thus obtained are called "center of lift curves." We find on these curves all the properties of the Eiffel curves. For a given center of lift, the equilibrium is stable only when the curve of the center of lift has no branches corresponding to unstable equilibriums.

It is thus seen that the Hanriot airplane is stable below 8° and above 13° (descending branches of the curve) and is unstable

between these limits (ascending branches of the curve). With the center of pressure at 30%, it is always stable.

The Eiffel curves present discontinuities which disappear in the center-of-lift curves. These discontinuities are replaced by a crossing center of the corresponding curves for the Hanriot airplane at an angle of attack of 2°, i.e. at the ordinate of the asymptote of the Eiffel curves relative to the angle of attack for which the resultant is parallel to the axis of the propeller.

Similar verifications may be made on diagrams of the Henri Paul airplane (Figs. 3 and 4).

Practical Applications.

In order to determine experimentally the center-of-lift curve of an airplane, it is only necessary to find, for different speeds, the angles of attack of the wings and the corresponding positions of the elevator. It is possible to determine these for angles of attack between 0° and about 15°.

If it is noted that it is only necessary to know the course of the curve to conclude whether the airplane is stable or not, it is evident that the variable angle of attack may be replaced by another variable varying in the same direction, which is the case of the relative speed.

For the different speeds under these conditions, the pilot determines:

1. The relative speed, by means of a tachometer;

2. The angular position of the elevator by means of a pointer

moving in front of a dial and connected with one of the elevator controls (guignols) by means of an inextensible wire held by a spring. The control stick might serve the purpose, but the readings would be vitiated by the play of the controls (commandes). Note that all these indications may be recorded, if necessary, in order to serve for control. We thus have all the necessary data for drawing the center-of-lift curve of the airplane. The examination of this curve will show immediately whether the airplane is stable. From it there is likewise deduced the direction of the necessary correction in the contrary event.

Take, e.g., the case of the Henri Paul airplane. The first test with the center of lift at 40% gives the maximum curve. The airplane is therefore unstable at small angles of attack and the center of gravity must be moved forward. The second test with the center of lift at 30% gives a curve indicating good stability.

It may be of interest to find whether the center of gravity may be given some intermediate position between 30 and 40%. A test is made, e.g., at 35%. If the curve still has an ascending branch, the center of gravity is too far back. Otherwise, the center of lift is correct.

It is thus seen that, with the aid of a few experiments, the best position for the center of gravity can be determined with precision and in a logical manner. This method may be employed in all cases, both with test airplanes and with used airplanes.

In the former case, the result obtained enables the constructor to determine the position which the wings must occupy with re-

spect to the fuselage and, consequently, to specify definitely the structural details of the parts of the assembly.

In the latter case, it enables the determination of the change in the center of lift caused by the gradual distortion, due to fatigue, of the various parts of the airplane.

The methods of adjustment now employed do not suffice for correcting the defects of a large number of airplanes. Some means of shifting the whole or a portion of the wing structure must therefore be provided, as was done in the beginning of aviation. Only in this way, can airplanes stand long usage.

Practical Center-of-Lift Tests.

If an airplane has a propeller whose line of thrust passes through the center of gravity, the presence of the thrust does not interfere with the tests. The practical procedure must, however, be the same as though this were not the case. The tests are divided into two series: gliding tests and tests under power.

The former show whether the wings are well located. The air-speeds and the positions of the elevator are recorded during flight at a constant R.P.M.

The latter tests show the disturbing effect of the thrust. It is interesting to make them under normal flight conditions, e.g., in horizontal flight at different altitudes, at different speeds, or in climbing under full engine power.

Examination of the curves shows whether it is possible to correct the disturbing influence of the engine by inclining its

supports so as to modify the change in the center of lift couple resulting from the action of the propeller thrust. The importance of these tests is therefore obvious.

This method, which was invented in 1916, in order to correct the center of lift of an airplane which had often given trouble, was investigated by the Eiffel laboratory, which felt the necessity of supplementing its aerodynamic reports with stability diagrams.

These diagrams have the form indicated in Figs. 1 and 3. We consider the curves of Figs. 2 and 4 of the most immediate utility, because they conform the closest to experience in flight.

We are thus led to the conclusion that the adoption of this method of testing would render great service to airplane constructors, as well as to civil and military inspectors, who have to make navigability tests of airplanes in use.

Moreover, by direct application of the results obtained in the laboratory, it would enable a closer coöperation of the laboratory and the airport, which cooperation is becoming more and more necessary for facilitating the progress of aviation.

Translated by the National Advisory Committee for Aeronautics.

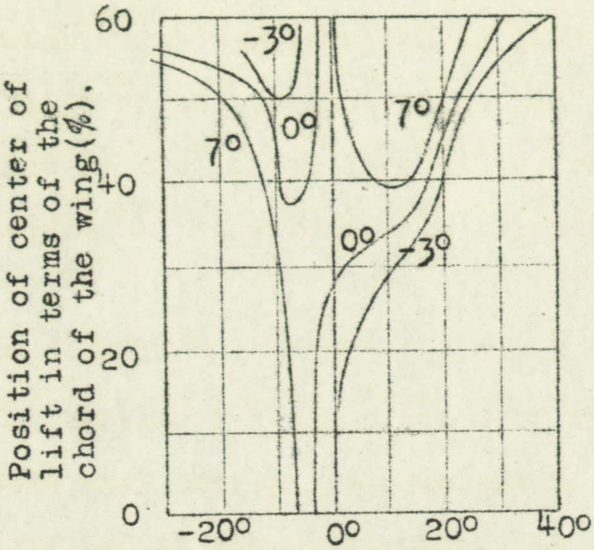

Fig.1 Angle of attack

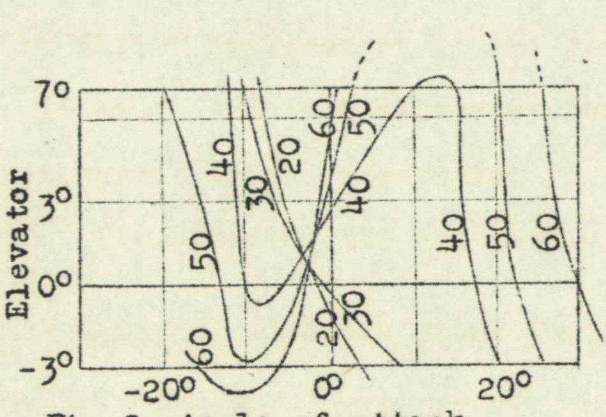

Fig.2 Angle of attack

HANRIOT AIRPLANE

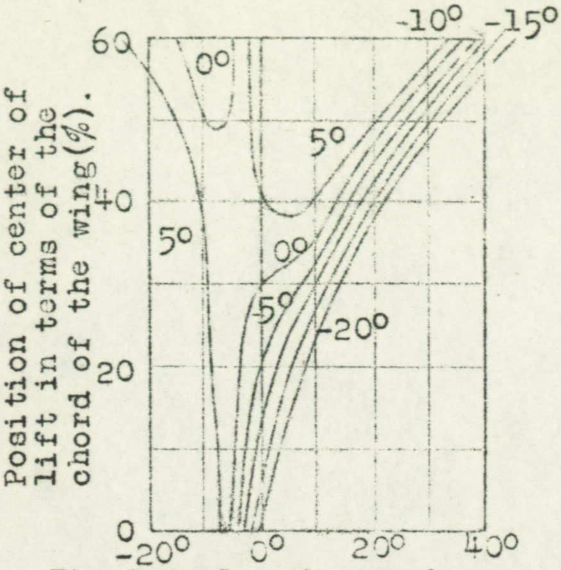

Fig.3 Angle of attack

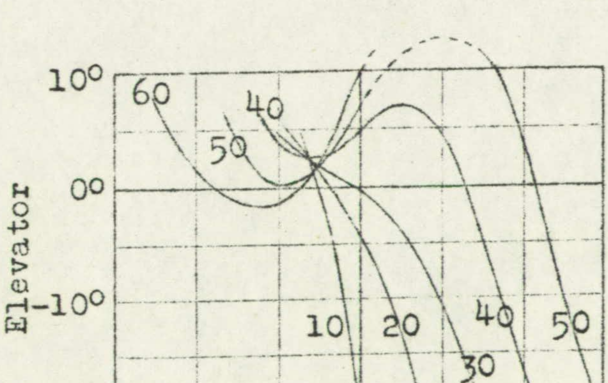

Fig.4 Angle of attack

HENRI PAUL AIRPLANE